INNOVATIVE SOFTWARE FOR EXISTING BUILDING ENERGY ANALISIS

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Abstract

The software is designed to analyze energy options of large multi-building portfolios. It models building energy end-use and savings breakdowns based on advanced weather statistics, tuned utility data, and weighted building system performances. The paper describes the modeling concepts and main features.

Introduction

Energy analysis of a complex energy retrofit for multi-building portfolios is a complicated task. The existing software and simplified engineering methods provide calculations only for one building. However, weather, cost rates, typical measures and other data are often common for the whole portfolio. Moreover, manipulation of energy figures on the portfolio scale level would be beneficial in making technical and financial decisions. These considerations stimulated development of an expert system capable to quickly analyze large number of buildings simultaneously based on a common database housing weather and building energy-related data.

Common methods of individual building energy analysis used by ESCO are based on calibrated hourly simulation and disintegration of yearly utility data into end-use breakdown. Both methods are time-consuming processes with results highly affected by numerous assumptions.

Simulation software like DOE, HAP, TRACE and others /1/, /2/, /3/, /4/ were designed to simulate *new* non-existent buildings. An attempt to calibrate the simulated energy use of an *existing* building to its historical energy data inevitably involves iterations with intuitive tune up of the inputs. Given significant uncertainty of existing building input data, the impact of user perceptions on calibration makes the simulation results much uncertain. A difference between the simulation and actual weather data adds up to the uncertainty introduced by assumptions.

The simplified engineering methods based on end-use construction inherit the same problem. Measure energy savings often calculated by inconsistent in-house mathematical models are checked for sanity through energy end-use breakdowns intuitively tuned based on vague audit data. The uncertainty is expected to be greater than of the simulation due to use of the primitive mathematical models unable to account for system interactions and other substantial characteristics of the building processes.

Moreover, management of massive building, weather, and utility information by common computing means creates problems of storage, sorting, update, transfer and other data processing.

Below we describe software designed to address the discussed problems.

Building energy analysis concepts

The Energy Data Management System (EDMS) includes a set of modules developed in MS-SQL database and C++ .Net platform allowing for efficient data storage, processing, and upgrades. Current version of EDMS includes Weather and Energy modules. The first module deals with weather data import and normalization to the format required for energy analysis. The weather data is downloaded from an energy accounting software or a text file to calculate actual and normalized heating- and cooling degree days. Normalization means averaging HDD and CDD for a selected year range to account for the latest weather change tendency. The normalized HDD are used to calculate:

- the most probable pre-retrofit energy use not biased by a particular year
- the heat transfer through envelope components.

To calculate ventilation latent loads a statistical correlation between dry- and wet-bulb temperatures is applied (figure 1). As you can see from the regression analysis, the correlation goodness is 99% and can be used for calculation of humidity ratios (HR) associated with bin- dry-bulb temperatures.

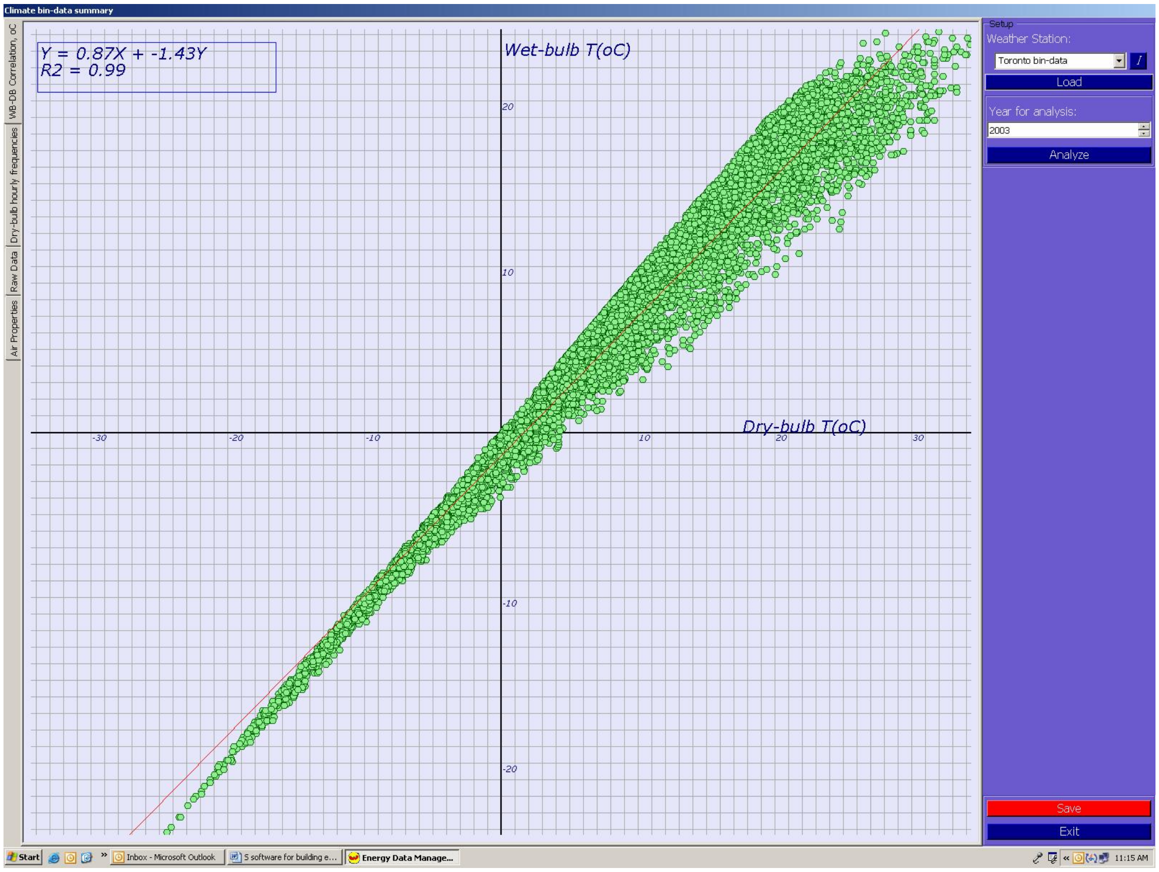


Figure 1. Dry-to wet-bulb temperature correlation interface of the Weather Module.

Similar to heating and cooling degree days, we introduced weather statistics reflecting cumulative outdoor humidity conditions driving humidification and dehumidification of buildings

For dehumidification **HR- Days = ∑ (HR - BHR)** **if BHR>HR**
For humidification **HR– Days = ∑ (BHR - HR)** **if BHR<HR**

Where **BHR** is a balance humidity ratio (similar to the balance temperature) calculated based on the maintained indoor humidity level and internal moisture gains.

The Energy Module performs utility data processing and building energy analysis. One of the key principles of the energy analysis is a descendent breakdown of the yearly energy consumption into components (the total building energy into non-weather-sensitive and weather-sensitive parts, the latter into transmission, infiltration, and ventilation loads etc). Common intuitive process of the energy end-use breakdown is replaced by *calculation* of the component weights based on their relative performance.

Categorizing of building zones, systems and measures by their energy pattern allowed for accommodation of various systems and measures through a limited set of inputs. For example, all building spaces and rooms receiving energy from heating and cooling plants are grouped into a set of typical zones heated and cooled by a certain plant type. The total building area is disintegrated by the following dimensionless equations

Fuel-heated zone % + Electrically heated zone % + Heat pump heated zone % = 100%

Air-conditioned zone % + Non-air-conditioned zone % = 100%

Thus, instead of detailed data on every single room in the building, the area percentage of typical zones is entered.

Performance inputs of the representative plants (primary energy source equipment) are calculated to provide the same impact as the actual plants on the total heating and cooling energy. The calculation is based on weighted ratios of the actual plant performances rated to the served areas. The rational is to account for the fact that, for example, 50% of the building area served by an electric boiler has different electricity use than other 50% served by a heat pump with HCOP>1. Similarly, actual secondary equipment is organized to be described by a set of models reflecting the equipment impact on the respective energy end use component. This approach allows to reduce inputs and to calculate various equipment except for cogeneration plants and absorption chillers.

Development of numerous models covering all possible measures is not possible. Instead, a set of typical measure models with calculated inputs is developed. Measures are grouped by their impact on the building systems. As a result of grouping, the measure inputs are reduced significantly and various combinations of measures can be accommodated. To improve accuracy, yearly building energy balance is applied to calculate cumulative impact of energy conversion measures (for example, increase of gas use and reduction of cooling load due to lighting load reduction).

Inaccurate audit data is still the main source of uncertainty. A method of the uncertainty calculation was developed to estimate the risk of retrofit underperformance due to both inaccurate audit data and methods of savings verification. This feature is not a part of current EDMS version yet.

The software has been tested for extreme input conditions (stress test) and compared against common engineering calculations. The tests verified that EDMS produces steady rational results sufficient for everyday engineering practice.

EDMS features

The software was designed for multi-user application to analyze buildings with complex interactive energy saving measures and to provide unique database for weather, utility, building, system, and measure data stored by portfolio with options to customize reports.

EDMS performs the following logical steps of energy data processing:

1. Import, diagnostics, and statistical analysis of weather data
2. Import, diagnostics, and correction of utility data
3. Base year period selection
4. Meter data tune up
5. Building energy end use and measure savings breakdown

The first step includes set up of a weather station, quality control of the downloaded weather data, calculation of heating/cooling degree-days and humidity ratio –days.

At the second step building, meter, and bill data downloaded from an energy accounting software are tested for inconsistency and the detected errors are reported before importing is allowed. For diagnostics and review purposes the bill datasets are screened in a dot-field matrix by meter names and bill dates as shown in figure 2.

Each dot contains a full set of bill information that can be viewed and, if needed, automatically or manually estimated. EDMS evaluates bill data against the rational range of energy cost rates and magnitude of monthly use and cost variances. The hi/low range limits are set up manually. If a bill does not comply with the limits, the dot color turns from grey to red allowing user to spot the questionable bill.

Use/day and Cost/day monthly trends shown by the bar charts are followed by the statistically averaged trends shown with blue polynomial curves indicating the expected trend values. The red bars indicate that the bills belonging to the highlighted meter exceed the variance limit. The graphical interface for detection of questionable bills was designed for quick manipulation of massive bill information.

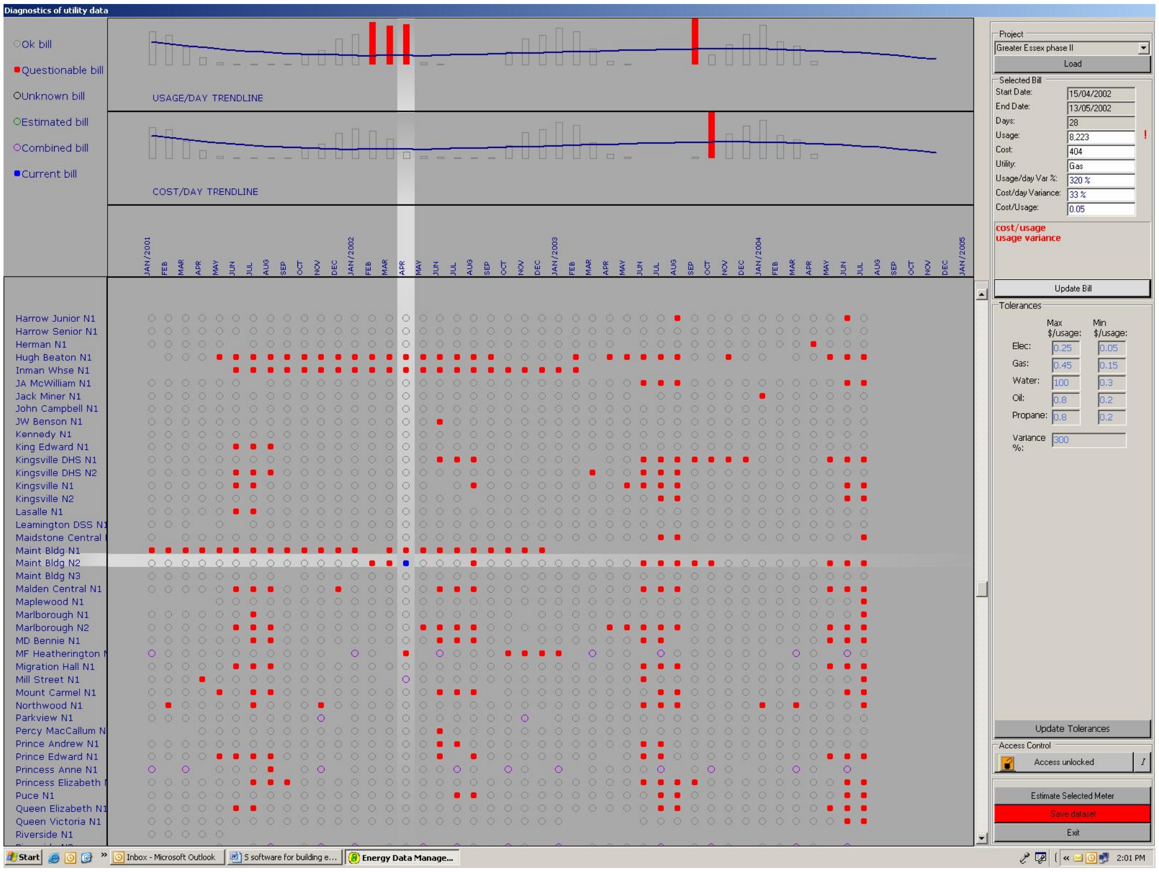


Figure 2. Bill data diagnostics interface

The third step is selection of the most reasonable base year period among the whole historical energy data available in the database based on the tendency of meter and portfolio year-to-year non-weather sensitive energy use. The process is automated and visualized by screening bill dots having one of the following colors (figure 3): grey circled dots reflect valid bill data; dark grey dots indicate that bill data is missing; and blue dots show bills falling into a selected year period. The yearly energy trend is analyzed by individual meter and by portfolio. The check boxes on the right hand side allow the selection of one of the methods of calculating portfolio yearly use. The selected period can be tuned up by portfolio or meter.

Some of the meters with poor data or out of the retrofit scope can be excluded as shown by the red marks. The selected period is locked out from change by other users.

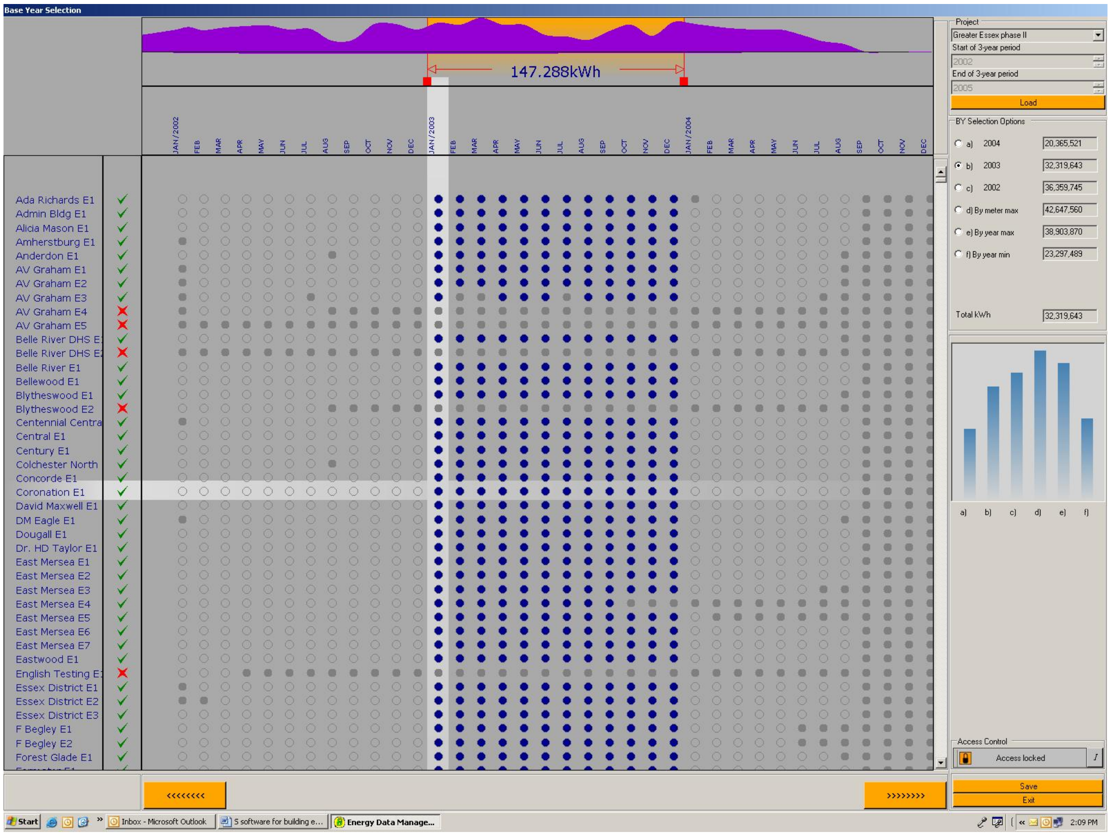


Figure 3. Base year period selection interface

The fourth step is weather sensitivity analysis of the meter data fallen into the selected base year period. If correlation of the meter data with weather is strong, the correlation coefficients and normalized heating degree-days are used to tune up the yearly meter use. If not, the actual meter data is tuned up to 365 days only. The screen in figure 4 allows for user control of the regression analysis.

A portfolio name, weather station, and initial balance temperature can be selected from the drop down menu. The button Analyze forces EDMS engine to tune up all the meters at once. Then a building meter is picked up for individual adjustment. The screen shows the selected bill data, correlation coefficients, and other pertinent information required for visual control.

The energy analysis interface shown in figure 5 is a multi-tab screen allowing template-based building and system data entry by portfolio with individual tune up and simultaneous review of inputs, interim, and final calculations for a selected building. Unlimited number of templates by building category can be entered, edited, and automatically applied by building, building group, or portfolio to relieve input entry.

The left hand side tabs include input data grouped by category. For example, the top tab depicts the normalized pre-retrofit yearly energy use and the correlation statistics.

Categorized measure inputs are entered as a percentage of the impacted energy end use reduction. Currently, the impact value is calculated by Excel spreadsheets, if higher accuracy is required. EDMS upgrade in 2006 will have a new module housing specific system and measure details used to *calculate* the categorized measure inputs.

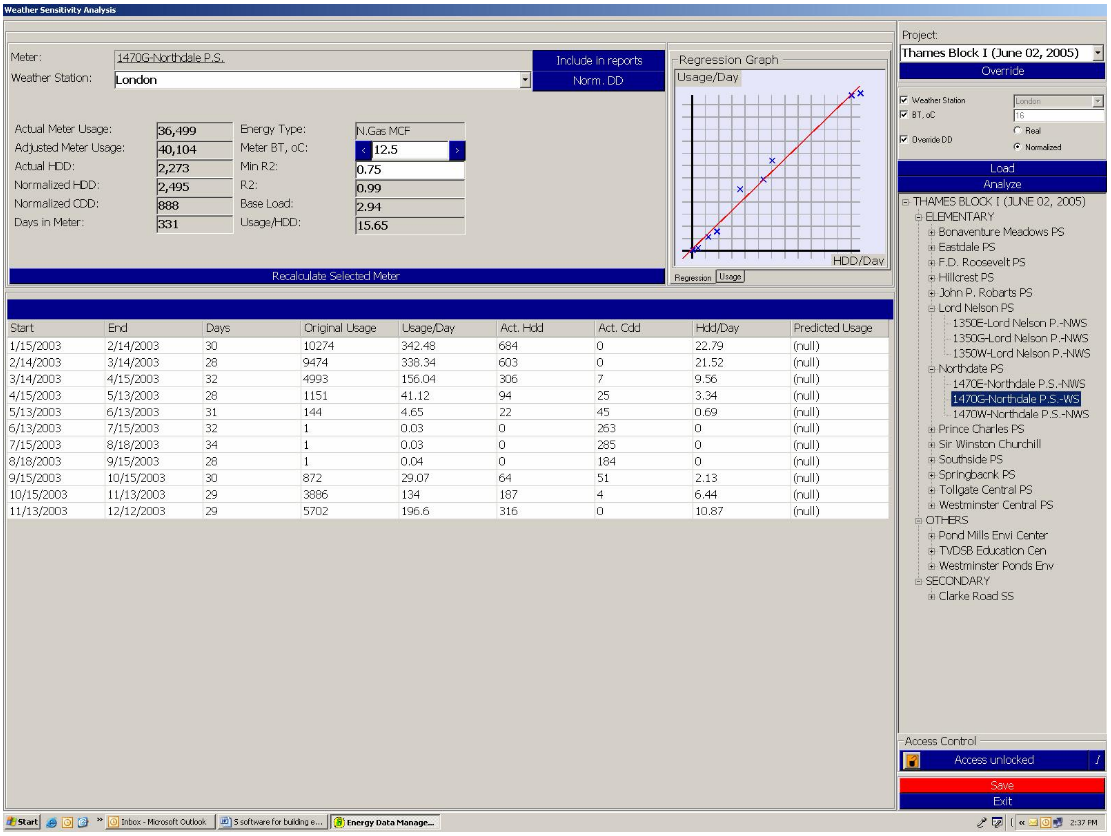


Figure 4. Meter regression analysis interface

Thermal Loads tab indicates the envelope heat loss breakdown, and the actual and calculated overall envelope performances. Building input data is tuned to calibrate the calculated value. The calibration imposes restrictions on usually intuitive input manipulation and, thereby, assures better accuracy of calculations.

Cooling Loads tab reflects the cooling loads breakdown. It is shown for additional sanity control.

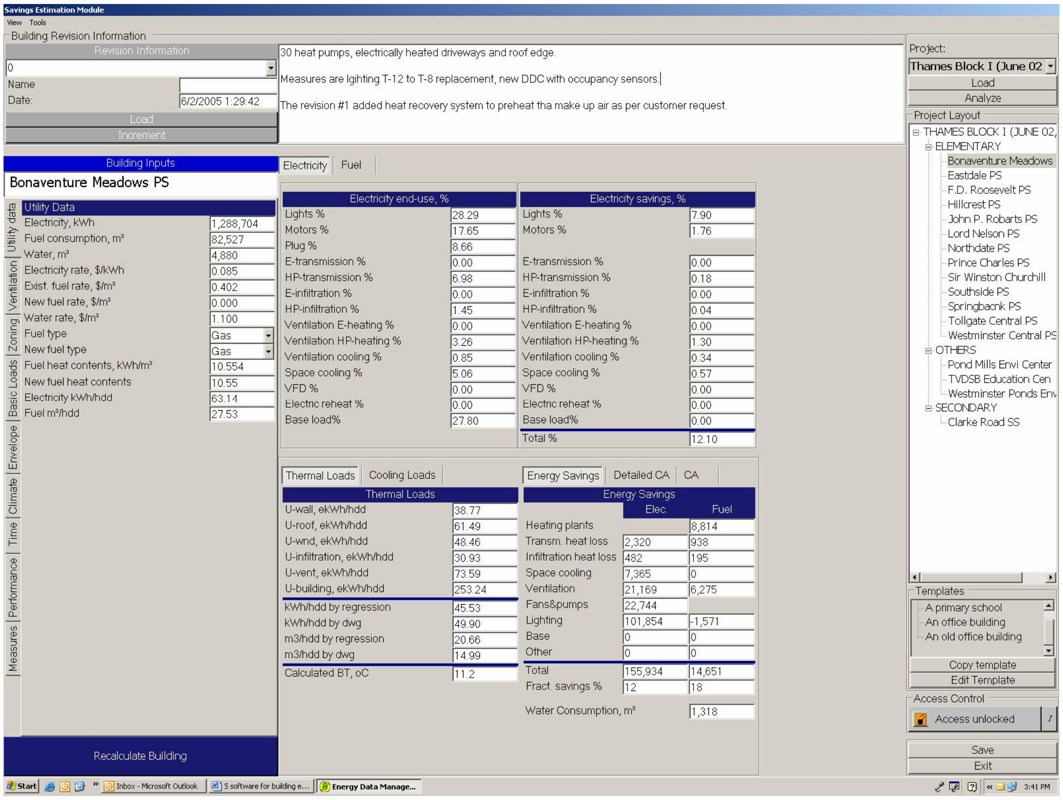
The Electricity and Fuel tabs represent the building electricity and fuel end-use breakdowns and the associated energy savings in percentages. The letters F, E, and HP refer to electrical, fuel, and heat pump heating.

The Energy Savings, Detailed and Total Cost Avoidance (CA) tabs reveal the savings in energy units and dollars.

If an alternative measure scope is intended, EDMS allows for entry of *a revision* copying the original building inputs as a new dataset with a further option to change them. The revision option allows for comparison of energy retrofit alternatives and tracking of the historical measure scope and energy savings change.

The Report Manager module developed with Crystal Reports software allows for comprehensive and customized reporting indicating all the steps of data manipulation ranging from bill ledgers to building and portfolio energy use and savings summaries.

EDMS has been used for energy retrofit and renewal programs of various school boards in Ontario.



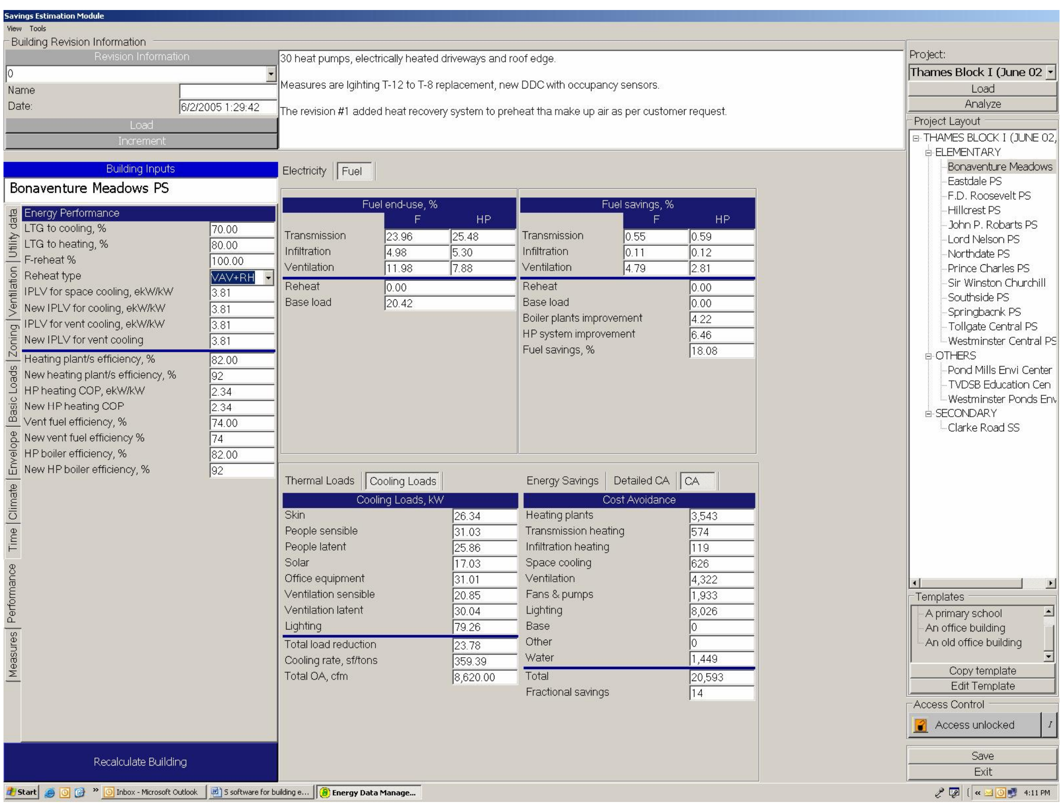


Figure 5. Building energy analysis interface

An example of alternative energy retrofits analysis

A school board including 56 buildings with total area of 2,270,000ft^2 consumes 23,210,000kWh of electricity and 2,231,000m3 of gas at operational cost of $3,041,575. The following energy retrofit and renewal scenarios are considered:

Scenario 1: Lighting T-12 to T-8 fixtures retrofit and weather-stripping for windows and doors.

Scenario 2: Replacement of old central controls and heating boilers added to the scenario 1.

Scenario 3: Conversion of the electrically heated portion of the buildings to natural gas added to the scenario 2.

The table below summarizes comparison of the scenario energy savings calculated by EDMS.

Scenario	Electricity, kWh	Gas, M^3	Cost avoidance $	Operational cost reduction	Retrofit cost, $	Simple payback
1	4,500,000	50,000	446,250	15%	2,093,000	4.7
2	5,660,500	650,100	781,535	26%	9,733,000	12.5
3	9,142,000	244,300	960,103	32%	17,033,000	17.7

Selection of the appropriate scenario can be based on the best return of investment (scenario 1) or age-related criteria (scenario 2 or 3).

Software benefits

- Ability to analyze energy use and reduction options for multi-building portfolios
- Improved accuracy of energy calculations
- Reduced risk of energy retrofit underperformance
- Efficient building data management
- Multi-user application with central data storage
- Flexible and customizable reporting.

References

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